(12) UK Patent Application (19) GB (11) 2 306 365 (13) A

(43) Date of A Publication 07.05.1997

(21) Application No 9621416.8

(22) Date of Filing 14.10.1996

(30) Priority Data
(31) 9521571 (32) 20.10.1995 (33) GB

(71) Applicant(s)
The Welding Institute

(Incorporated in the United Kingdom)

Abington Hall, Abington, Cambridge CB1 6AL, United Kingdom

(72) Inventor(s)
Wayne Morris Thomas
Peter Temple-Smith

(74) Agent and/or Address for Service
Gill Jennings & Every
Broadgate House, 7 Eldon Street, LONDON, EC2M 7LH, United Kingdom

(51) INT CL^6
B23K 20/12

(52) UK CL (Edition O)
B3R RK R15

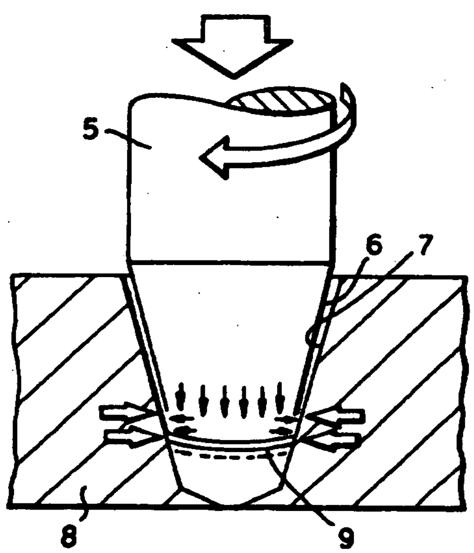
(56) Documents Cited
GB 2268430 A GB 2233923 A

(58) Field of Search
UK CL (Edition O) B3R
INT CL^6 B23K

(54) **Friction plug extrusion**

(57) A method of forming a plug-like member comprises placing a consumable member (5) in a bore (7) of a substrate (8) so as to leave a clearance between the consumable member and the wall of the bore. Relative movement is caused between the consumable member (5) and the substrate (8) while urging them together to generate frictional heat and fully plasticizing the consumable member across the bore in a plasticised region which progresses along the consumable member in a direction opposite to the urging direction. The plasticised material (9) is allowed to solidify so as to form the plug. Each of the consumable member and bore are tapered at different angles. Alternatively the plug may have a different cross section from the bore, eg hexagonal.

Fig.3(B).



GB 2 306 365 A

Fig.1.

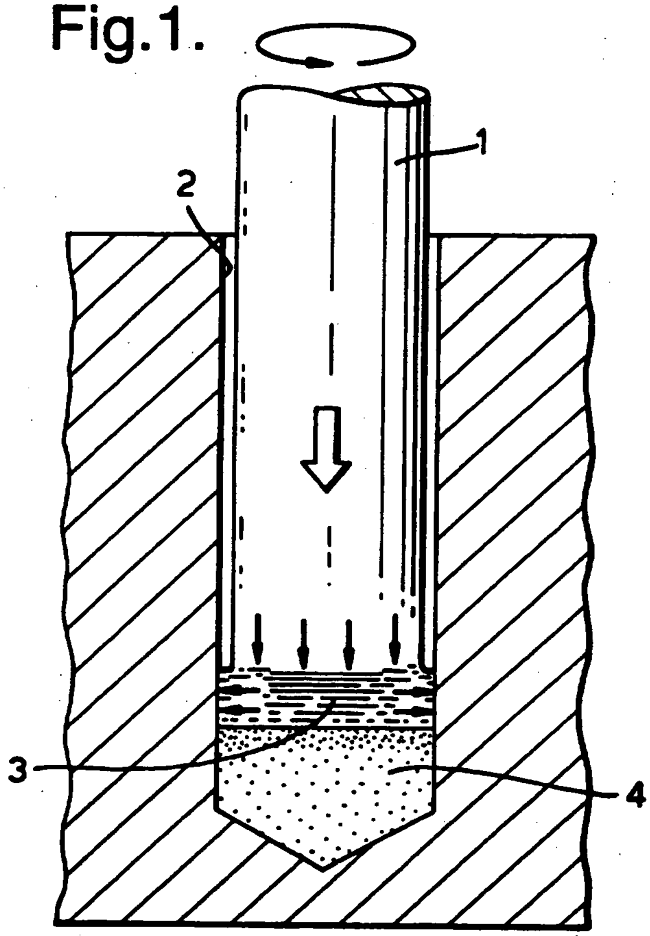


Fig.4.

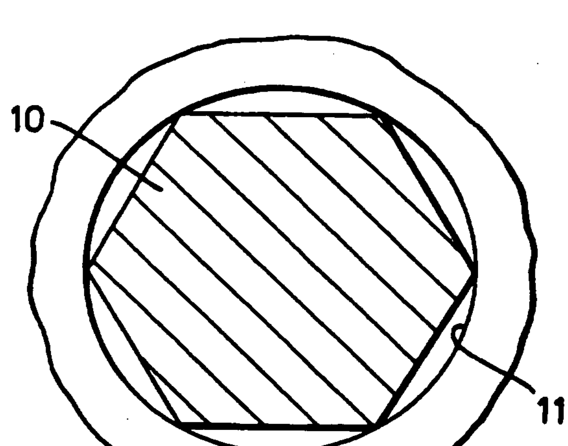


Fig.2.

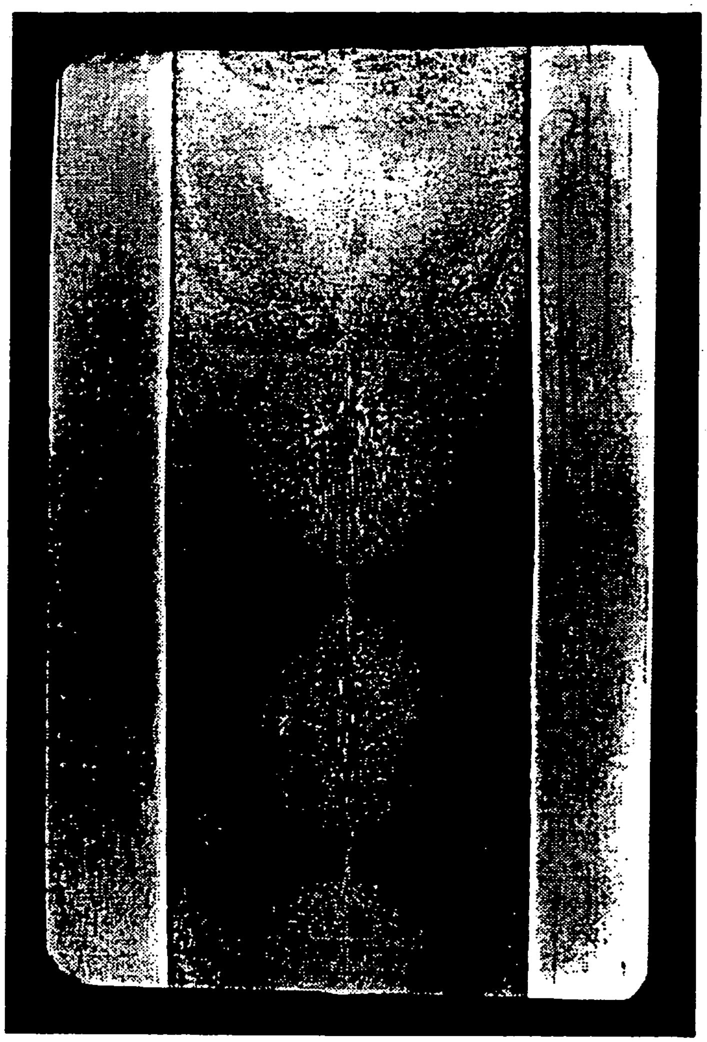


Fig.3(A).

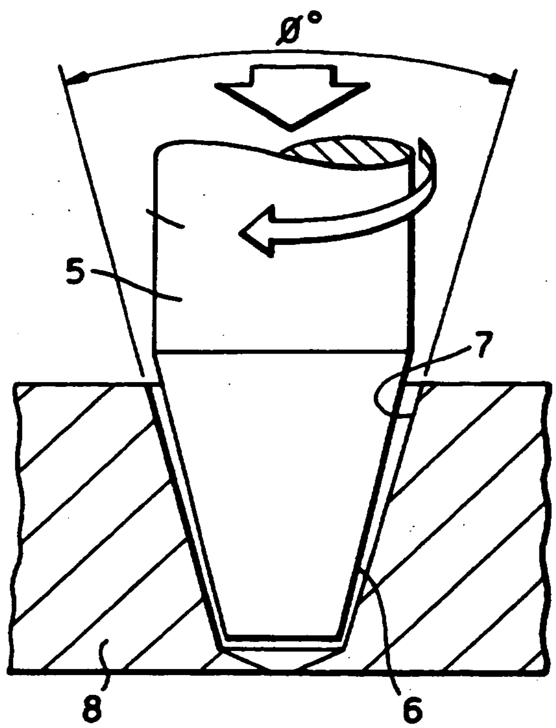


Fig.3(B).

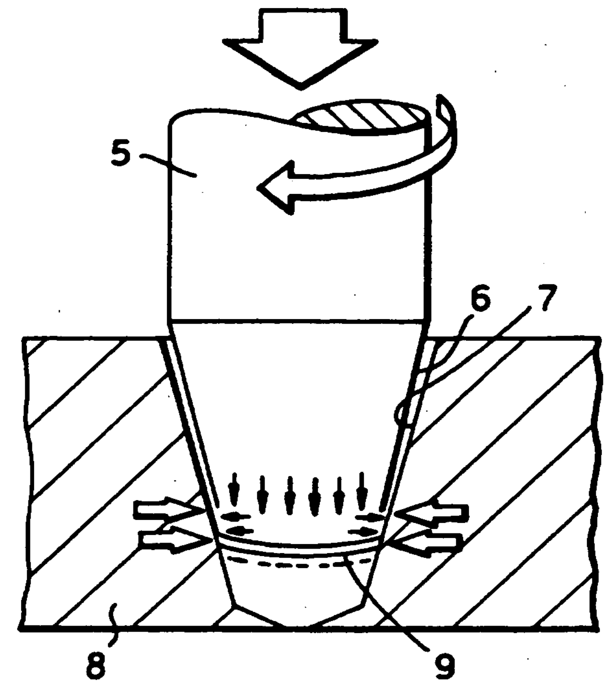


Fig.3(C).

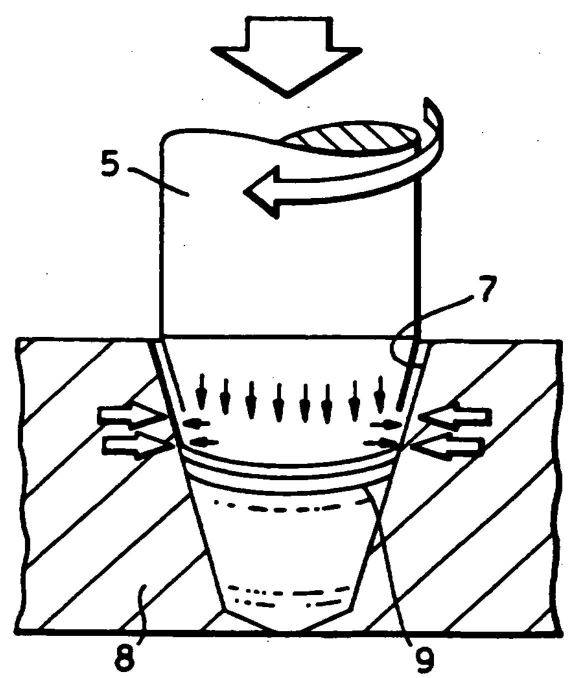


Fig.5.

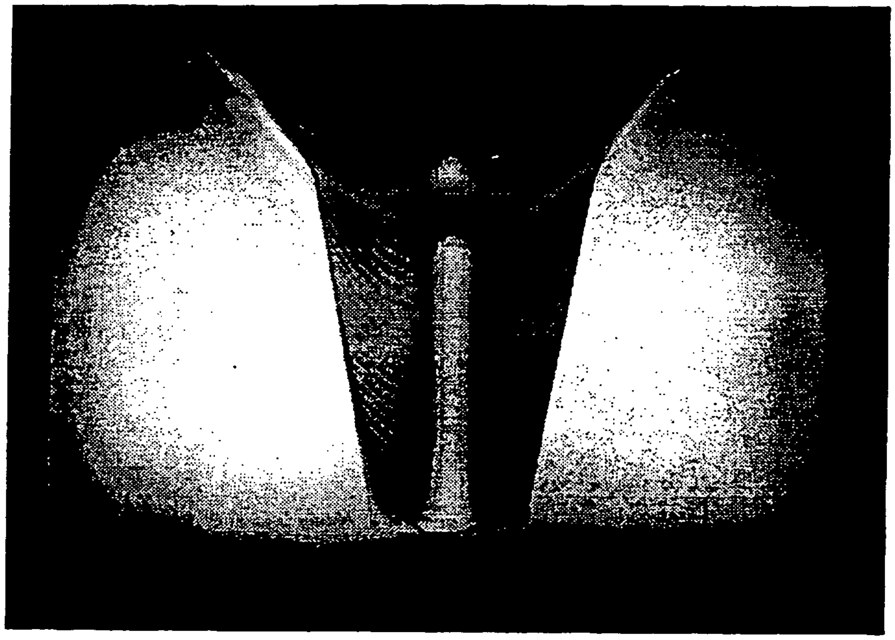
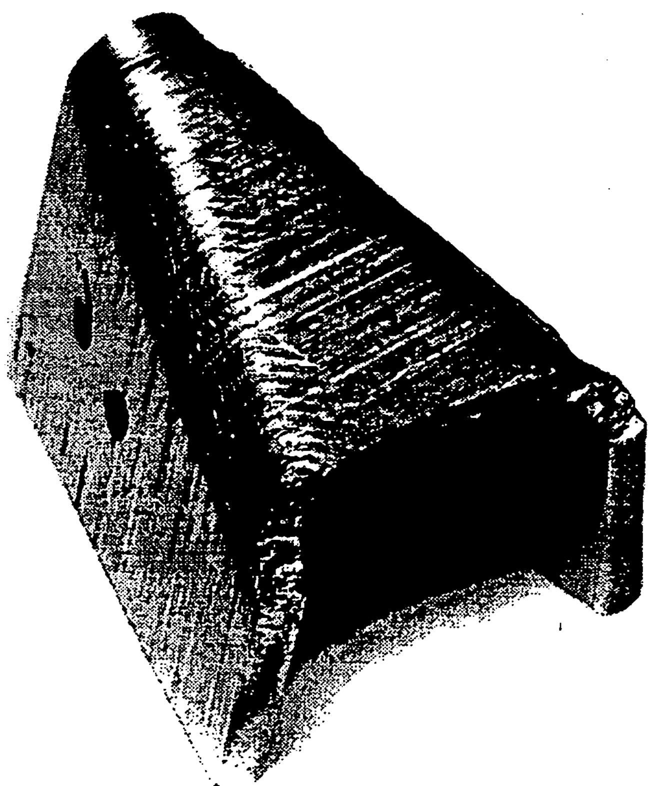


Fig.6.



2306365

IMPROVEMENTS IN FRICTION PLUG EXTRUSION

Materials joining is a key enabling technology which impacts competitiveness and reliability in almost all manufacturing sectors. Virtually all manufactured products are made from components which must have been joined. Continuous improvements and effective application of emerging technology for joining are essential for manufacturers to remain competitive.

The recorded use of frictional heat for solid-phase joining techniques dates back over a hundred years. More recently work on new techniques now allows solid-phase friction welding to be applied to sheet and plate material as a viable option for plate fabrication in a range of materials.

Friction hydro pillar processing (FHPP) is a comparatively recent solid-phase welding technique described in WO93/04813. This technique is the focus of considerable R&D interest because of its potential in fabrication and manufacturing where it offers a number of novel production routes. The FHPP technique shows promise for joining and repairing thick plate in ferrous and non-ferrous materials. Conventional fusion welding of thick section fabrications involves lengthy processing sequences and with some process large volumes of consumable material. In contrast, use of the FHPP welding technique should provide a reduction in joint preparation and weld filler metal, which will lead to significant cost savings.

As shown in Figure 1, the FHPP technique involves rotating a consumable rod 1 coaxially in a circular hole 2, under an applied load to continuously generate a plasticised layer 3. The layer 3 consists of an almost infinite series of adiabatic shear surfaces. During FHPP the consumable is fully plasticised at the frictional interface across the bore of the hole. This interface travels through the thickness of the workpiece or rod 1. The plasticised material develops at a rate faster than the feed rate of the consumable rod 1. This means that the

friction rubbing surface rises along the consumable 1 to form a dynamically recrystallised deposit material 4. The plasticised material at the rotational interface is maintained in a sufficiently viscous condition for hydrostatic forces to be transmitted, both axially and radially, to the bore of the parallel sided hole 2 enabling a metallurgical bond to be achieved. Since this material is being forced hydrostatically into the surrounding bore, the diameter of the deposit material is nominally greater than the feedstock material.

Very good quality FHPP welds have been produced, using a parallel hole geometry, in steel and certain non-ferrous materials, and these have been characterised by good impact, tensile and bend results.

Sudden changes in microstructure are sometimes observed, and are considered to be the result of an almost instantaneous shift in the rotational frictional interface. The rotating consumable is believed to seize at its current frictional interface (rubbing surface) and then shear at a location some distance further along the consumable, creating a new frictional interface. This effect is shown in Figure 2. If sufficiently large, the area between these periodic interfaces shows little sign of extensive plastic deformation, even though the bond is good. (The bond between these regions of partially transformed consumable material is comparable with that of a normal friction weld.) Presumably, if the hydro pillar processing action forces sufficient softer material between the rotating consumable and the side of the hole (i.e. back extrusion of plasticised material), the area of frictional contact will increase. This additional area under frictional contact will lead to much higher torsional resistance, which can cause the area of weakest shear strength to move to a point further along the rotating consumable. This effect is particularly noticeable in parallel hole welds where a comparatively high rotation speed and a high consumable displacement (burnoff) rate were used.

In ideal conditions, the distance moved by the rotational frictional interface should be very small, giving an almost continuous movement of a series of shear interfaces along the weld.

This invention relates to the so-called friction plug extrusion process otherwise known as friction hydro pillar processing (FHPP) in which a consumable bar is inserted into an enclosing cavity and pressed against the bottom (or an end wall) and rotated while maintaining pressure to generate sufficient frictional heat for the end of the bar in contact with the base to be softened to generate plasticised material which proceeds to fill the cavity. In particular the invention relates to means for reducing the tendency for the bar to shear across its own cross section, rather than at the operating rotational interface which latter takes up an approximately hemispherical shape during the progress of the plasticised material as deposited. This tendency is related to the aspect ratio of the cavity: the smaller the diameter and deeper the hole the greater the tendency. In the process according to the prior art the deposited plasticised material fills the cavity progressively as the bar is consumed. The refined material is of value in itself as its structure is much finer than the conventional structure of the wrought bar or cast material. Alternatively the process can be used to join together the plasticised material as deposited with the surrounding cavity to form an integral component.

In the latter case for improved side wall bonding it is desirable to use as high a rotational speed as possible which leads in turn to a less viscous and hence higher temperature plasticised layer and a considerable degree of working adjoining the wall of the containing cavity. In some cases with the high rotational speeds the rate of forward movement of the consumable bar is insufficient to compensate for the heat flow back along the bar and the consumable bar develops regions of lower shear strength than the original cold material. In particular with the

approximately hemispherical rotational interface as developed in the FHPP. The torque required at the rotational speed concerned is greater than the shear strength of the bar material.

Under these conditions the process can jump or interrupt leaving substantially original bar material in contact with the plasticised layer as deposited, together with a fresh interface developing on the sheared plane of the consumable bar. The sequence of progression of heat build up and weakening of the bar stock together with a restart of the process in a zone further back than the desired frictional rotational surface is repeated.

This effect can also be caused by excess plasticised material under a hydrostatic pressure being extruded in the gap between the consumable bar and the containment cavity. This extruded hot material again serves to soften the bar by thermal contact. In addition the extruded material passing up the sides of the consumable bar in the gap increases the local friction which again contributes to further heating of the bar stock.

In accordance with one aspect of the present invention, a method of forming a plug-like member comprises placing a consumable member in a bore of a substrate so as to leave a clearance between the consumable member and the wall of the bore; causing relative movement between the consumable member and the substrate while urging them together to generate frictional heat and fully plasticizing the consumable member across the bore in a plasticised region which progresses along the consumable member in a direction opposite to the urging direction, allowing the plasticised material to solidify so as to form the plug like member having an outer surface conforming to the inner surface of at least part of the bore; and either leaving the plug-like member in situ or, following formation of the complete plug-like member, removing the substrate, wherein each of the consumable member and bore are tapered at different angles.

With this arrangement the tendency for weakening of the consumable or bar is overcome and the process of depositing plasticised material can be maintained without interruption. In one method the bore or cavity is arranged as a shallow cone with a low total included angle while the consumable also is of conical form but with a total included angle slightly less than that of the surrounding cavity. As will be appreciated the cross section offered by the bar or consumable increases with progression along its length and hence even at reduced shear strength it can provide sufficient torque to maintain the operating rotational interface as desired.

The difference in the two conical angles is such that a relatively small gap is maintained near the operating end of the consumable bar but that a larger gap exists further back along the bar. This larger gap both reduces the tendency for the plasticised material to be extruded in the space between the consumable and the surrounding cavity.

In accordance with a second aspect of the invention a method of forming a plug-like member comprises placing a consumable member in a bore of a substrate so as to leave a clearance between the consumable member and the wall of the bore; causing relative movement between the consumable member and the substrate while urging them together to generate frictional heat and fully plasticizing the consumable member across the bore in a plasticised region which progresses along the consumable member in a direction opposite to the urging direction, allowing the plasticised material to solidify so as to form the plug like member having an outer surface conforming to the inner surface of at least part of the bore; and either leaving the plug-like member in situ or, following formation of the complete plug-like member, removing the substrate, wherein the consumable has a different cross-section to the bore.

For example, the consumable may have a polygonal cross-section. In this case the bar or consumable is parallel sided but shaped to provide working space to

reduce the tendency for the plasticised material to fill the gap between the bar and the enclosing cavity.

For example a bar with a hexagonal cross-section gives rise to free space over the flats while maintaining sufficient working of the plasticised material to the extreme corners or full width of the bar concerned. Moreover under these conditions the surrounding cavity can be relatively close fitting since the bar only touches at the corner extremities of its section and the total frictional heat so produced is not excessive. The cross section of the bar may also be an alternative polygonal shape such as square, pentagonal etc.

Alternatively the bar may have a knurled end. In a further alternative the bar may have a series of parallel grooves or a single helical groove (i.e. threaded).

Typically gas shielding is employed as part of the process.

These and other arrangements are within the scope of the invention which aims to prevent failure of the consumable across sections other than the operating rotational interface and hence maintain a continuous formation and deposition of plasticised material in the cavity concerned.

These and other aspects are apparent from the following illustrations in which:-

Figure 1 is an example of the friction hydro pillar process (FHPP) according to the prior art;

Figure 2 is an example of breakdown and restart of the FHPP in operation in which a low carbon steel consumable is welded to a stainless steel tube, both having cylindrical sections;

Figures 3A-3C illustrate one method for reducing the tendency to interruption;

Figure 4 is a cross-section through one example of an alternative method with a hexagonal bar;

Figure 5 is a macrosection showing a successful FHPP deposit made in accordance with an example of the invention; and,

Figure 6 is a view similar to Figure 5 but of another example.

In Figures 3A-3C, successive stages in a welding process according to an example of the invention are shown. Initially, a consumable 5 having a tapered leading section 6 is inserted into a bore 7 of a substrate 8, the bore 7 being tapered at an angle slightly greater than the taper angle of the leading end of the consumable member 5. The consumable member 5 is rotated at relatively high speed while being urged into the bore 7 thus creating a plasticised region 9 as shown in Figure 3B. As rotation and urging continues, the plasticised region 9 rises up the consumable member 5 as shown in Figure 3C so that gradually the consumable member 5 is welded into the bore 7.

The use of a tapered hole 7 together with a tapered consumable 5 enables a reactive force as well as hydrodynamic force to be exploited in making the joint. This variant of the technique enables FHPP welds to be made in materials regarded as difficult to extrude or flow at forging temperature. The geometry is such that a nominally uniform gap is maintained between the changing cross-section of the consumable and the changing hole diameter during the welding operation. If the angle of the taper is too obtuse, the deposited pillar material will not climb. The angle of the taper will to some extent be material-dependent, i.e. the relative ease with which the material can be conventionally extruded may be a feature worth noting. Current indications are that included angles of less than 30° for certain copper alloys and angles of less than 25° for aluminium alloys would be preferred. Typically, in the case of aluminium, the bore has an internal angle (ϕ) of 20°, and the consumable member has an internal angle of 17°.

The use of tapered holes and correspondingly more acute tapered consumables reduces the tendency for large shift in the location of the rotational interface to occur. The taper pillar welding technique allows comparatively higher rotational speeds and higher consumable displacement rates to be used than are possible with parallel holes and parallel consumables.

As well as providing a reactive support, tapered holes and tapered consumables provide an increasing cross-sectional area of correspondingly increased strength. In addition, the diverging gap above the interface tends to prevent the back extrusion of plasticised material, again reducing the tendency for large changes in frictional interface location.

Figures 5 and 6 show the result of taper welding a 6082 aluminium alloy consumable into a 6082 aluminium substrate.

The FHPP weld cycle would benefit from a comparatively high consumable rotational speed for a short touch-down conditioning period, followed by a lower rotational speed for the main pillaring period, and finally by an even lower consumable rotational speed for the end part of the weld cycle. This applies to parallel and taper geometries. The higher rotational speeds for the initial part of the weld cycle would quickly raise the temperature of the comparatively cold substrate and consumable. A lower consumable rotational speed at the end part of the weld cycle would generate a thicker plasticised layer which, in turn, would fill any depression which can occur with a single speed weld cycle.

FHPP is an asymmetric process; depending on the elasticity of the material and the length of consumable stick out, the consumable may torsionally twist along its unsupported length. However, for consumables with short stick out, torsional twisting can be regarded as insignificant. With respect to material deposition, the friction rotational interface preferentially travels

towards the relatively smaller mass consumable bar by a continuous helical shear. Heat flow and thermal conduction causes the rubbing surface to be partially spherical in shape, as shown in Figure 5.

Figure 6 illustrates the FHPP technique being used to butt weld steel plates.

Experimental work has shown that good mechanical integrity can be achieved. Impact tests have demonstrated that a significant improvement in toughness properties can also be achieved, e.g. low carbon steel consumable material before FHPP gave impact properties of 31 Joules kV while the same material after FHPP gave deposit core impact properties of 115 Joules kV.

Metallographic examination has shown that the FHPP deposit material is hot-worked with very fine grained microstructure.

The process advantages can be summarised as follows:

- deep penetration narrow gap technique
- low cost (bar stock) consumables
- environmentally friendly process
- repair technique
- rapid - 100mm deep holes can be filled in less than 20 seconds
- suitable for magnetically hostile environment.

The process can be considered for:

- One-sided rivetting of plates
- Repair of localised lamellar tearing and cracks
- Mechanical locking device
- Repair of wrongly positioned, drilled holes.

Figure 4 illustrates an alternative example in which a consumable 10 has parallel sides and a substantially hexagonal cross-section and is inserted into a cylindrical bore 11 of a substrate. The polygonal (hexagonal) cross-section of the consumable 10 means that edges of the

consumable will rub against the bore 11, at least initially, thus promoting the FHPP process.

CLAIMS

1. A method of forming a plug-like member, the method comprising placing a consumable member (5) in a bore (7) of a substrate (8) so as to leave a clearance between the consumable member and the wall of the bore; causing relative movement between the consumable member (5) and the substrate (8) while urging them together to generate frictional heat and fully plasticizing the consumable member across the bore in a plasticised region which progresses along the consumable member in a direction opposite to the urging direction, allowing the plasticised material (9) to solidify so as to form the plug like member having an outer surface conforming to the inner surface of at least part of the bore (7); and either leaving the plug-like member in situ or, following formation of the complete plug-like member, removing the substrate, wherein each of the consumable member and bore are tapered at different angles.

2. A method according to claim 1, wherein the taper angle of the consumable member is less than the taper angle of the bore.

3. A method according to claim 2, wherein the taper angle of the bore is less than 30°.

4. A method according to claim 3, wherein the taper angle of the bore is less than 25°.

5. A method according to claim 4, wherein the taper angle of the bore is substantially 20°.

6. A method according to any of the preceding claims, wherein the taper angle of the consumable member is less than the taper angle of the bore by at least 3°.

7. A method of forming a plug-like member, the method comprising placing a consumable member in a bore of a substrate so as to leave a clearance between the consumable member and the wall of the bore; causing relative movement between the consumable member and the substrate while urging them together to generate frictional heat and fully plasticizing the consumable member across the bore in a

plasticised region which progresses along the consumable member in a direction opposite to the urging direction, allowing the plasticised material to solidify so as to form the plug like member having an outer surface conforming to the inner surface of at least part of the bore; and either leaving the plug-like member in situ or, following formation of the complete plug-like member, removing the substrate, wherein the consumable has a different cross-section to the bore.

8. A method according to claim 7, wherein the bore has a circular cross-section and the consumable member a polygonal cross-section.

9. A method according to claim 8, wherein the consumable member has a hexagonal cross-section.

10. A method of forming a plug-like member substantially as hereinbefore described with reference to any of the examples shown in Figures 3 to 6 of the accompanying drawings.

The Patent Office

13

Application No:	GB 9621416.8	**Examiner:**	Dave Butters
Claims searched:	1-6,10	**Date of search:**	30 December 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): B3R

Int Cl (Ed.6): B23K

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2268430 A (FRICTEC)(see figs 8C,8D)	1,2
X	GB 2233923 A (WELDING INSTITUTE)(whole doc')	1-6,10

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.